Modeling of wood under combination of normal stresses with rolling shear stress

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Variation of material properties and strength of wood in its three main directions is large and mainly depends on the cellular structure of wood, the geometry of wood cells [1] and their orientation. The anisotropic behavior leads to several different failure mechanisms already under uniaxial stress. Multiaxial stress analysis becomes important when dealing with modeling and design of certain engineering details and the local material behavior. Research regarding material behavior of wood under stress combination, especially interaction of shear stress with normal stresses in the transverse plane has however attracted less attention. Even, the current Euro-code EC5 also lacks [2] of such a design model to account for the combination of stresses perpendicular to the grain with shear. The Swiss standard for the design of timber structure, SIA 265:2003 [3] however includes design criteria for stress perpendicular to the grain in combination with shear, which was developed for longitudinal shear. The work presented herein aims at defining a material model for wood under compression perpendicular to the grain with rolling shear interaction by means of finite element (FE) modeling. It considers geometrical nonlinearity, which makes the model suitable for analysis on the structural scale to have an in-depth insight of local stress distribution. The FE material model was compared with experiments by modeling a biaxial test setup and comparing numerically determined stresses with strain fields measured in experiments.

Experiments were realized in biaxial test frame with a setup, consisted of steel plate with mechanical grip to hold and connect the specimens with the test frame. Displacements in two perpendicular directions were prescribed for testing under different stress combinations. Experiments were carried out on two series of dog- bone shaped, Norway spruce specimens. In addition to force and displacement measured by the internal actuator of the biaxial test frame, a digital image correlation (DIC) technique (Aramis, GOM) was used to measure strain fields on one surface of the specimens by continuously capturing images during the experiments.

FE modeling was analyzed in Abaqus (SIMULIA[TM] by Dassault Systemes®) for compression, shear and different stress combinations of compression and shear stresses in radial-tangential plane. A 3-D model was considered with symmetry in one plane to reduce the number of elements and computational cost. Orthotropic material behavior was considered by defining elastic and plastic properties of wood in three principal directions. Material behavior was defined by means of a user-defined subroutine considering elastic and plastic material model with hardening and densification regions under compression orthogonal to the fiber direction.

The numerical model shows suitable correlation with experiments under uniaxial compressive and pure shear loading. Influence of annual ring orientations and differences in earlywood and latewood material response are observed in experiments in all loading cases. The biaxial experiments confirmed the positive influence [2] of the interaction of rolling shear with compressive stress in the failure of materials. However, in the FE model, the beneficial effect of shear interaction in case of combined loading is not reflected as well as in experiments. Consideration of one global hardening parameter to define the material behavior under compression and shear in different anatomical directions could be the reason. Consideration of annual rings, its curvature, and variations of material behavior i.e., earlywood and latewood region could improve the results in the biaxial case. However, consideration of different hardening parameters or fitting the failure criteria with experiments under such stress combination is an extremely demanding task.

References

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